63-3-4

⑤ 728/00

①

403 807

S-610 - #4 (.n.
⑮ Contract DA19-12 ᵕ -81C
Quantum Inc.

AD No. 403807
ASTIA FILE COPY

⑦ NA
⑧ U
⑨ Report No. 4 (Final)
5 Jun 61-4 Jun 62
⑩ by J. F. McLean
⑪ 4 Jun 62.
⑫ 50p.
⑬ NA
⑭ S-610
⑯ see 3rd sheet
(17-19) Nit
㉑ U
㉒ NA

⑥ Literature Survey of Viruses
and Rickettsia in Foods

Period: 5 June 1961 - 4 June 1962

④
$5.60

AD _____ Accession No. _____
Quantum, Inc., Wallingford, Conn.
CONTAMINATION OF FOODSTUFF BY
VIRUSES AND RICKETTSIAE-J. F. McCrea
Report No. 4 (Final), 5 June 1962
50 pp., 3 tables, 120 references
Contract DA-19-129-QM-1810 (OI 5116)
Project No. 7-84-01-002

This report is the first known compre-
hensive review of those viruses and
rickettsiae which may contaminate food
and which may subsequently initiate
infection in man. There are 10 viruses
and 1 rickettsia which have this cap-
ability. Milk is the most frequent ve-
hicle for virus infection in man. The
total inactivation dose recommended is
$5x10^6$ roentgens for all viruses except
infectious hepatitis. For this virus a
dose of $2x10^7$ roentgens is recommended.

AD _____ Accession No. _____
Quantum, Inc., Wallingford, Conn.
CONTAMINATION OF FOODSTUFF BY
VIRUSES AND RICKETTSIAE-J. F. McCrea
Report No. 4 (Final), 5 June 1962
50 pp., 3 tables, 120 references
Contract DA-19-129-QM-1810 (OI 5116)
Project No. 7-84-01-002

This report is the first known compre-
hensive review of those viruses and
rickettsiae which may contaminate food
and which may subsequently initiate
infection in man. There are 10 viruses
and 1 rickettsia which have this cap-
ability. Milk is the most frequent ve-
hicle for virus infection in man. The
total inactivation dose recommended is
$5x10^6$ roentgens for all viruses except
infectious hepatitis. For this virus a
dose of $2x10^7$ roentgens is recommended.

CONTRACT RESEARCH REPORT

Quartermaster Food & Container Institute
for the Armed Forces, Chicago

Hq. Qm Research and Development Command
QM Research & Development Center, Natick, Mass.

Quantum, Incorporated
Lufbery Avenue
Wallingford, Connecticut

Project Nr.   :   7-84-01-002
Contract   :   DA 19-129-QM-1810
Report Nr.   :   Final
Period   :   5 June 1961 -
                   5 June 1962

Initiation   :   5 June 1961
date

Official Investigator : J. F. McCrea

Collaborator   : R. F. Horan

Title of Contract: Literature Survey of Viruses & Rickettsiae
                    in Foods

PART I

INTRODUCTION

The presence of viruses and rickettsiae in food and milk may occur in two ways:

1. As far as animal products are concerned, the animal itself may be infected and, therefore, infect its products used for human consumption. Foodstuffs, in this instance, are infectious by primary contamination.

2. Accidental contamination of foodstuffs and milk by man, animals or insects which causes the secondary contamination of products used for human consumption.

The evidence for the transmission of any one virus or rickettsia through food or milk has been divided into four classes:

Class I   Direct isolation of virus or rickettsia from the foodstuff, supported by unequivocal laboratory evidence.

Class II Isolation of virus from patients, with clear-cut epidemiological evidence of infection through food; or unequivocal clinical diagnosis of viral disease in man, supported by clear-cut epidemiological evidence.

Class III Presumptive clinical and epidemiological evidence of viral infection through food.

Class IV Viruses that are present in food, but for which there is no evidence for the initiation of disease in man.

Following an exhaustive literature survey, we have recorded our

classification of viruses and rickettsia in foods in Table I.

TABLE I

CLASSIFICATION

	Class I	Class II	Class III	Class IV
Primary Contamination	Q fever Russian tick-borne complex Foot-and-mouth dis. Rabies		Coxpox	Newcastle dis.(?) (experim.)
Secondary Contamination	Poliomyelitis	Infectious Hepatitis	Epidemic diarrhea (viral) Lymphocytic choriomeningitis smallpox, vaccinia	

Poliovirus

There is strong epidemiological evidence from several countries that polio-

virus is transmitted by unpasteurized or imperfectly pasteurized cow's milk

(1,2,3,4,5,6,11); but in no case has the virus itself been isolated in the

laboratory directly from the milk. For example, 62 cases of poliomyelitis

occurred within 5 days in Broadstairs (England) in 1927, mainly involving private

boarding schools having little communication with the town or with each other.

Approximately 90% of these cases had drunk milk from one dealer, and four

individuals who drank milk supplied by this dealer developed the disease after

leaving Broadstairs. The milk was pasteurized by the "flash" method only during

hot weather. No illness resembling poliomyelitis had occurred in any of the

dairy workers or milk handlers (1). A smaller epidemic (eight cases) in Spring

Valley, New York, involved residents in three widely separated boarding
houses who drank milk supplied by one dairyman. This dairyman kept
two cows under highly insanitary conditions, the milk and utensils
being exposed to flies. A boy living in a house 50 feet from the dairy
was ill with poliomyelitis shortly before the outbreak of the epidemic.
It was concluded that flies carried the virus from the sick boy to the
dairy, and that milk so contaminated transmitted the disease to the
other cases, all of which had their onset within three days. Others
who consumed the same milk after boiling it were unaffected.(2). In
another New York State epidemic, eight cases of poliomyelitis developed
among consumers of milk from a dairy where a worker milked cows and
handled the milk for four days while in the acute stage of poliomye-
litis (6). "Explosive" epidemics of this type, with the majority of
patients consuming raw milk from a single source, constitute strong
presumptive evidence of milk-borne viral infection, even though the
virus was not isolated from the milk, the patients, or the flies (3).
In one instance, lemonade handled by a girl during four days immediately
before she developed poliomyelitis appeared to be the vehicle for
poliomyelitis which subsequently developed in 14 children who either
drank the lemonade, or were in close contact with those drinking it (7).

References to the transmission of poliomyelitis in solid foods are
rare. Bananas and fly-bait (bananas plus liver or fish with water) were
exposed for 24-48 hours in the houses of poliomyelitis patients in
the South of the U.S.A. and then fed to chimpanzees: The chimpanzees
developed subclinical infections or asymptomatic carriers states (10).

An outbreak of 23 cases of poliomyelitis in Cornwall (England) showed
a high correlation between the illness and consumption of pastries from
a particular bake house. It was suggested that artificial cream in
the pastries carried the virus (4). (Note: The author of this paper
in a personal communication (May 1962) now doubts the connection between
the pastry and the disease.) Fish in rivers polluted with sewage,
along the banks of which flies were collected which carried polio-
virus, could not be shown to be infected with the virus (9).

It may be concluded that poliovirus can be transmitted by raw
cow's milk, which becomes infected either by direct contact with a
human case excreting the virus, or by flies carrying the virus from
human excreta. Boiling or efficient pasteurization of infected milk
inactivates the virus.

Infectious Hepatitis

Infectious hepatitis is a viral disease spread almost exclusively
by fecal-oral routes. As far as is known at present, man is the only
host. The most important vehicles of transmission are food and water.
Research on this virus has been severely handicaped until very recently
because there was no method of cultivating it in the laboratory, and
consequently tests for the presence or absence of virus had to be
carried out on human volunteers. At the end of 1961, Rightsel et al
(19a) described cultivation of several strains of IHV in the Detroit
6 (PD) line of cells, and transmission of the virus from tissue-
culture to man. Although these results are regarded with some scepti-
cism by other workers in the field, it seems highly probable that at

least some strains of the virus have been cultivated in the laboratory.
Studies on the transmission of the virus will thus be enormously
facilitated. All the work described in this report was carried out
before IHV was grown in tissue-culture, and hence in no instance is
there direct laboratory evidence of isolation from food. The epidemio-
logical evidence of transmission through sea-food(and also through water)
is, however, very strong.

Oysters. Within the last ten years, several relatively large out-
breaks of IH have been traced to the consumption of raw oysters. In
Sweden, 119 cases of IH occurred between December 18, 1955 and January
26, 1956; in every case oysters had been eaten less than one month
before the onset of disease. The infected oysters were definitely
traced back to two distributors, who stored oysters in the harbor
which was heavily contaminated with sewage. A worker in one of the
oyster packing houses was known to have had IH during November, 1955.
Sewage from the packing house ran directly into the harbor. Oysters
consumed immediately after arrival, which had not been stored for some
time in harbor water, did not appear to carry the virus (19). An
earlier Swedish epidemic of some 600 cases was also traced back to
consumption of oysters. Unsuccessful attempts were made to discover
if the virus multiplied in the oysters themselves (12b). In the U.S.,
several cases of IH in Connecticut in 1961 were connected with raw
oysters (18), and in Pascagoula, Mississippi, approximately 70% of
persons in a small epidemic had eaten raw oysters 15 to 50 days before
the onset of symptoms. Most of these oysters were derived from a

single bed situated about one mile from the city raw sewage outlet (14, 14a). This outbreak, together with concurrent though smaller epidemics in Mobile and Troy, Alabama, constitute the first transmission of IH by oysters recorded in the U.S.A. (14a).

Clams. Many cases of IH have had their origin in clams obtained from the East Coast of the U.S., particularly from New Jersey (13) and Connecticut (18). Approximately 50% of several hundred cases studied in New Jersey during the first four months of 1961 had recently eaten raw clams (13). Almost 90% of these clams could be traced to Raritan Bay, which receives large volumes of sewage from New Jersey and also New York (12a, 13).

Milk. An outbreak of 10 cases of IH occurring in Georgia in 1945 appeared to be very probably connected with consumption of raw milk from a single dairy. Two cases of IH occurred in a house adjoining the dairy, a common surface toilet was situated 100 feet from the area where milk was handled under unhygienic conditions, and water for washing utensils was obtained from a shallow well less than 100 feet from the toilet (16). Although milk has often been suspected of carrying IHV, little specific evidence is available (21).

Other Foods. Explosive outbreaks of IH have occurred among people eating together in institutions of various kinds, but the actual food carrying the virus has seldom been identified. Thus, 24 cases of IH occurred within 10 days among members of a university fraternity house; all patients had eaten one or two meals together over a short period.

No illness was reported among employees handling food (17). Thirteen persons in a hospital developed IH, and in this instance two kitchen employees showed evidence of recent infection with the virus (12a).

The extensive epidemics of infectious hepatitis that occurred among troops at Alamein during the desert campaign of 1942 were due to the virus being carried by flies from excreta to food and eating utensils (15). Vegetables may readily become contaminated in countries where human feces are used as fertilizer (20).

Sewage and human excreta in general obviously constitute the main source of infection with IHV. Theoretically, any type of food or drink could be contaminated by a food handler excreting the virus. The isolation of the virus from food has now become a possibility since tissue-culture is available to assay IHV. The consumption of raw oysters, clams, or other sea-food which has been grown or stored near sewage outlets is a distinctly hazardous passtime.

As mentioned by Mason and McLean (14a), "oysters and clams are the only types of seafood commonly ingested uncooked. They are also one of the few food items in which the entire animal including the gastrointestinal tract and its contents are eaten. These two facts in combination with the ecology and physiology of these shellfish, uniquely equips them for transfer of disease with a fecal-oral route of spread."

Epidemic Diarrhea - Viral Gastroenteritis

There is some experimental evidence that both epidemic diarrhea of the newborn, and also certain types of gastroenteritis of adults

and children, are viral diseases spread by the fecal-oral route
(22, 23, 24, 25, 26). At present it is difficult to investigate the
spread of these viruses in food because laboratory identification of many
of them is not yet possible (31). In a general survey (34) of the causes
of diarrhea in 1958, 39% of cases were attributed to enteroviruses,
namely ECHO viruses (31%), Coxsackie viruses (5%), and polioviruses (3%).
Coxsackie viruses may be important because they are resistant to heat,
and are protected against thermal inactivation in the presence of milk,
cream, or ice-cream (35). The ECHO and Coxsackie viruses, resemble
polioviruses in many ways, and hence may possibly be also carried in
milk. Many other types of food (e.g., meat, poultry, fish, salads,
desserts) are considered likely to be passively contaminated with entero-
viruses (33). Epidemic diarrhea of the newborn is, of course, most
probably carried in milk and other fluids (31,34). It is likely that
recent developments in tissue-culture will lead to more thorough in-
vestigations of outbreaks of diarrhea, and to the identification of new
virus types and their modes of transmission.

Q Fever

Among the 33 papers on Q fever which have been summarized, the
great majority deal with the isolation of R. Burneti from cow's milk.
Q fever, therefore, is included in Class I as described above. Im-
portant studies on Q fever have been done in California. Beck and al
(39) in the Los Angeles area have shown that more than 50% of the raw
milk contains R. Burneti. Enright and al (45) were successful in
isolating C. Burneti in 33% of raw milk examined but in only 0.3% of
pasteurized milk (this positive finding was represented by only one

sample of pasteurized product which was half and half cream). Huebner and al (49) in Southern California, isolated R. Burneti from the milk of 4 widely separated dairies in Los Angeles County (40 out of 50 milk specimens were positive). In this county, 10% of all cows are constantly infected. Although human infection by dairy cattle is unusual in Northern California, Lennette and al (57) studied 29 human infections which occurred over 10 weeks in one dairying area. R. Burneti was found in pooled raw milk specimens from several producers and a high proportion of the animals comprising the herds from which these specimens were obtained was serologically positive. In Northern California, the seasonal occurrence of cases coincides roughly with the lambing season, a period when greatest contamination of the environment might be expected to occur through milk and placentas. In Southern California, dairy herds produce milk the year round (calving not seasonal) and cases of human Q Fever occur the year round also.

Luoto and al (60) note that epizologic studies have shown that of .60,000 dairy cattle shipped into Southern California annually between 40 to 50% acquire asymptomatic infection with Q Fever within 6 months after being brought into infected premises. These animals shed C. Burneti continuously or intermittently in the milk for periods of time exceeding one lactation period. In a study of the nationwide occurrence of Q Fever, the same author (59) mentions an increase in Q Fever in the Eastern USA since 1949 where 20 to 60% of the cattle are infected. In California, 98% of the cattle are infected.

In South West Texas, Irons and al (50-51-52) isolated C. Burneti from the milk obtained from 8 dairy herds. In one cow, all 4 quarters

of the udder were positive for the organism but in most instances, the positive findings were limited to one quarter of the udder.

In Wisconsin, Kitze (56) isolated C. Burneti from 7 out of 8 samples of milk obtained from cows with high CF antibodies (1:40-1:640). Out of 22,304 Wisconsin cattle sera tested for Q Fever, 1.2 to 22% were positive in different areas.

In Idaho, Stoenner and al (68) found that 26% of 333 persons associated with infected herds (herd milk found to be positive by capillary agglutination tests) had positive sera for Q Fever while only 14% of 394 persons incontact with Q Fever-free dairy cattle herds had positive sera.

Bektemirov and al (40) report from Crimea the isolation of 3 strains of R. Burneti from raw milk.

Investigators in Great Britain have also successfully isolated R. Burneti from cow's milk. In South Wales, Evans (46) found that 5% of the samples of raw milk from individual herds, 38% of bulked raw milk and 5.5% of pasteurized milk were positive for R. Burneti. Q Fever is, however, uncommon in South Wales. In South West Scotland, Grist (47) who isolated R. Burneti from raw milk reports that 0.8% of the cattle are infected with this organism. Marmion and al (61) studied an epidemic of Q Fever in Southeast Kent where there was a preponderance of raw milk drinkers among the Q Fever cases. The majority of the cases were among the customers of 5 dairies and C. Burneti was isolated from the milk of 2 of these dairies. The author reports also (62) on a fatal dase of Q Fever from Northeast Kent where the patient may have been infected by drinking raw milk which was shown to contain R. Burneti. In

another study of 69 sporadic cases of Q Fever identified at Cambridge
or Colindale, Marmion and al (65) report on the fact that 41% of the
patients drank unpasteurized milk and that R. Burneti was isolated in
the milk supplying 10 of them. In 13 cases in this series, there was
no obvious source of infection other than milk supply. In Devon and Kent,
6% of the herds excrete R. Burneti in their milk. In East Anglia, only
0.85% of the herds excrete the organism. The overall prevalence of
Q Fever in Great Britain is low because of the large numbers from areas
of low prevalence. The consumption of infected milk appears responsible
for sporadic cases of Q Fever (64). Is this due to the greater re-
sistance to infection of the oropharynx or intestinal tract as compared
with the lower reaches of the respiratory tract?

Slavin (66) who surveyed 3,374 herds in Great Britain concludes
that R. Burneti is present in the milk of 7% of the herds in England,
2% of those in Wales and 0.8% in Scotland. R. Burneti may persist for
3 years in the cow's udder. The author remarks that "the contact with
infected milk is probably more dangerous than drinking it and the handling
of a heavy udder oozing infected milk would account for many of the
slaughterhouse infections."

Abinanti (36) in a paper reporting on the presence of high Q Fever
antibodies in bovine whey obtained from milk containing R. Burneti states
that milk may be vaccinating more people than it is infecting. Along
the same line of thought, Stoenner and al (68) in an attempt to find
the reason for an apparent low morbidity for Q Fever among dairymen's
families mentions also that persons drinking raw milk from infected cows
may experience immunizing infections by the ingestion of rickettsiae

sensitized by coexisting antibodies in the milk.

BUTTER-CHEESE-CREAM. Babudieri (38) reports that R. Burneti in milk
are absorbed with the milk or alternatively, may contaminate butter,
cheese and cream. They survive for several days and even several weeks
in such foods. In cheese, the author found that C. Burneti is no longer
present after 46 days.

As far as butter is concerned, Jellison and al (53) in Southern
California isolated R. Burneti in fresh milk from a dairy in Los Angeles
County and in the buttermilk and butter obtained from this unpasteurized
milk. Refrigerated butter stored at below freezing temperature for 41
days after preparation was still infectious for guinea pigs and a passage
strain of R. Burneti was established from one of the test animals.

SHEEP AND GOAT'S MILK. R. Burneti has been isolated from sheep's milk
in Southern California by Huebner and al (48) and Jellison and al (55).
Beck and al (39) report on one Q Fever patient who used raw goat's milk
continuously for 5-6 years and another who used raw goat's milk in the
from of ice cream 2 weeks before onset of Q Fever.

In Northern California, Lennette and al (58) found that 38% of
the sera of sheep and 44% of the sera of goats epidemiologically linked
with human infection were positive for Q Fever. R. Burneti was isolated
from both sheep and goat's (57) milk in this area.

In Great Britain, Marmion and al (63) mention two sources of
Q Fever infection in the Romney Marsh district of Kent: sheep and in-
fected cow's milk. In South West Scotland, Grist (47) states that 0.7%
of the sheep are infected with R. Burneti. Slavin (66) in a review
article also mentions the isolation of R. Burneti from pooled milk of a

herd of goats in England.

Caminopetros (44) reports that R. Burneti has been isolated from milk of sheep and goats in Greece where dairy cattle are few.

Heat inactivation of R. Burneti

R. Burneti being such a heat resistant organism, pasteurization laws have to be reinforced. In Enright and al (45) paper, we read: It was agreed in the USA that milk should be pasteurized at 145^OF for 30 min by the vat method or at 161^OF for 15 seconds by the high temperature short time (HTST) method. No data were available relative to the effectiveness of these temperatures for the pasteurization of other dairy products. Since it is recognized that temperature slightly higher than 161^OF are required to destroy some microorganisms when they are suspended in products whose fat content is higher than that of milk or which contain added sugar (such as half and half cream, flavored milk, skim milk beverages), it was recommended that a some-.what higher temperature be used for the pasteurization of these products and an increase of an additional 5^OF to pasteurization temperature was suggested.

Raw Green Foods. These foods have been mentioned by Babudieri (38) as possible vehicles of Q Fever infection. Although infection through the alimentary tract, according to this author, is always possible, it requires large quantities of rickettsiae.

Beef Products. It is of interest that Bell and al (42) recovered R. Burneti from blood and numerous other tissues obtained from ex-

perimentally infected cows and therefore the contamination of meat
intended for human consumption remains a possibility. However, in
cows naturally infected with Q Fever, such a high degree of infection
is probably not obtained. This would account for the findings in
Southern California, of Huebner and al (49) and of Jellison and al (54).
The former investigator failed to recover R. Burneti from whole blood,
blood clots, urine and feces of a limited number of cows shedding
R. Burneti in their milk; the latter worker succeded in isolating
R. Burneti only in the cow's milk, udder tissues and supramammary
lymph nodes proximal to the udder but in none of the other tissues
tested.

Chicken and Eggs (experimental)

Sobeslavsky, in Czechoslovakia (67) isolated R. Burneti from
6 to 13 eggs laid by 2 experimentally infected hens between the 19th
and 42nd day after infection, and in 3 or 4 chickens between 2 and 55
days after hatching and the occurrence of transovarian transmission
was demonstrated.

Abinanti (36) also reports on the isolation of R. Burneti from
chicken eggs laid by hens which had been infected experimentally and
comments on the fact that it is interesting to speculate on the role
that infected eggs could play in the epidemiology of Q Fever if one
considers the resistance of the rickettsia to heat inactivation.

Human Milk. Babudieri (38) isolated on one occasion R. Burneti in
the milk of a woman who had become infected seven months earlier, and
had given birth about one month before.

Note: Although this report deals with the transmission of Q Fever

through milk and other dairy products and with the possibility of its

transmission through raw green foods, beef products, chicken and eggs,

it should be stressed that in most parts of the U.S. and also in

foreign countries, the most common mode of transmission is via the

respiratory tract.

Russian Tick Borne Complex.

In cross neutralization tests, the viruses isolated in 1953 from patients in epidemics of meningo-encephalitis in Slovenia and Austria were found to be indistinguishable from the agents called Russian Spring Summer Encephalitis (RSSE) virus, Czech encephalitis or louping ill virus, which are believed at the present time to be strains of the same agent (70). We shall therefore discuss these agents together.

The Czechoslovakian tick-borne encephalitis was first recognized in 1948 in the Strakonice area; in 1953 there was an epidemic of some size (69). Infection is usually contracted by the bite of ticks. In some instances, however, goat's milk has been suggested as the source of infection.

Ticks act as the indirect vector in the milk borne infections recently recognized by Smorodintsev and al. (72). So far, such infections have been related only to the ingestion of raw milk from goats infested with ticks in pasture.

Olitsky and Clarke in Rivers and Horsfall's Textbook (71), comment on the fact that these diseases of the Russian Tick Borne Complex are believed to result directly or indirectly from infected tick bites. They are rural rather than urban in distribution and the case distribution according to age, sex and occupation is determined by the closeness of contact with sources of infection, in particular, with forested areas. However, cases have occured among urban dwellers of all ages and either sex following visits to rural areas and milk borne infections have a familial group aspect.

Richling (70) during the 1953 epidemic in Styria, Austria, also

mentions cases of family contact, possibly through droplet or dust borne infection and a possibility of infection through foodstuffs. Three of the author's patients, all with the meningeal form of the disease, regularly drank milk from the same goat. Stilbans (quoted by Hloucal in Schweiz.Mediz.Wschr.1953, 83:78), also suggests that the disease can be transmitted in raw milk from infected goats (70).

Van Tongeren and al (73) report on an outbreak of encephalitis in Austria in 1954. Over 100 patients showed a significant rise of antibodies against the Graz strain of RSSB virus. About 60% of the cases gave a definite or probable history of tick bite. Another 18% may probably have been infected by drinking unboiled goat's milk and in about 20% of the cases, the source of infection is completely obscure. That unboiled goat's milk may be a source of infection was demonstrated in the author's case histories. In 2 families, each consisting of 3 persons (father, mother and daughter) and in an unattached old woman, the disease appeared nearly simultaneously in 5 out of these 7 persons who had only used unboiled goat's milk of the same 2 goats, and gave no history of tick bites.

In all 5 patients who had suffered from the disease, as well as in both goats, CF and neutralizing antibodies to RSSB were demonstrated. It is only in the case of consumption of unboiled goat's milk that the authors found 2 or more patients in one family.

As to how far cow's milk may play a part in the transmission of this spring summer encephalitis remains to be investigated. Neutralizing antibodies against the Graz strain have been demonstrated in sera of domestic cattle (73), also in goat, roe, hare, rabbit, chicken, pheasant and partridge. Of the goat sera examined, 65% had neutralizing

antibodies against the Graz strain of RSSB (73).

Verlinde (74) also strongly suspects, on epidemiological grounds, that unboiled goat's milk is a source of virus infection in man. In a study in Central Europe, 4 of 6 persons belonging to 2 families, and drinking raw goat's milk became ill without evidence of tick bites. Two of these patients developed CF antibodies.

In a goat experimentally infected with the Graz strain of RSSB virus high titer virus was recovered from the milk 4-5 days after infection and persisted until the 8th day.

As the author comments, these findings support the possibility that man could be infected by drinking such milk, particularly if there are abrasions of the mouth.

Foot-and-Mouth Disease.

Foot-and-mouth disease (FMD) is a highly contagious infection of cloven-footed animals, especially of cattle, pigs, sheep and goats, and it is rarely transmitted to human beings, who become infected by ingestion of virus contaminated food (meat), milk and dairy products, and also by handling the active agent or through contact with affected animals especially when abrasions in the skin are present.

That FMD may occur in man has for long been assumed. As quoted in a paper by Flaum (75b), over 100 years ago, Hertwig, Mann and Villain, tried to infect themselves by drinking the milk of an infected cow and were successful in doing so. The same paper refers to a case described by Fessler in 1934, where a woman developed a vesicular eruption on the hands after drinking raw milk some days previously. The diagnosis in this case, however, was not convincingly proven be-

cause of the incomplete laboratory studies. Flaum himself (75b)

describes 4 cases of FMD in man confirmed by animal experiments; al-

though infection through the skin of the finger was the most probable,

in two cases however, alimentary infection through milk was thought to

have occured.

Verge (76b) states that milk contained in the mammary glands of

an infected animal is infectious at an early stage of the disease and

parallels the viremia. Later, the milk also becomes contaminated with

virus contained in the vesicles on the udders when these get ruptured

through the milking process.

The work of several investigators are mentioned in Verge's paper

(76b)

> Terni and Lebailly showed clearly the presence of the FMD
>
> virus in the milk which is a reason for the spread of
>
> the disease and the death, sometimes unexpected, of
>
> young suckling animals.
>
> Trautwein and al established that milk was infectious in
>
> goats from the 13 to 113 hrs. following experimental in-
>
> fection.
>
> Andrews and his co-workers mention the irregularity with
>
> which the milk becomes infectious when obtained asepti-
>
> cally from the udders during the ruptive stage of the
>
> disease.
>
> Terbrüggen found that the virus remains resistant from
>
> 12 to 15 days in refrigerated milk; from 15 to 17 days in
>
> milk stored at $+4^{\circ}C$; from 25 hrs to 6 days in milk stored

at 17-20°C; from 32 to 43 days in dried milk, using the
"spray" method.

When not refrigerated, the virus of FMD remains virulent for an average
of 20 hrs. in whole milk, skimmed milk and butter milk.

Butter. According to V$_e$rge (76b) obtained from cream under normal
condition of lactic maturation is not infectious. On the other hand,
unsalted butter is apparently infectious for 8 days and, when salted,
for 9 to 14 days.

Cheese. The contradictory reports on the infectiousness of cheeses may
be due to the great variety or methods of processing cheeses. Verge
(76b) reports that they are not infectious but Van Rooyen and Rhodes,
in their textbook, (77) state that the usual source of infection in
cases of FMDV entering the body by the digestive tract is milk, butter,
cheese, or other milk products coming from diseased animals.

In Switzerland, Flückiger (ref. 76b) points out the fact that
dairies and cheesemongeries are playing an important part in the
spread of FMD, during the epidemic which occured around 1940.

Milk and its products (skimmed milk, butter milk...) contribute
greatly to spread the disease in regions with important milk in-
dustry. However, according to Flaum (75b), FMD remains a rare in-
fection in man. During the epizootic of FMD in Sweden in 1939, about
4300 herds of cattle were infected which implies that tens of thou-
sands of people must have come into the most intimate contact with
infected animals, not to mention all those who have drunk infected milk.
During this epizootic, altogether 8 cases of FMD in man have been fully

established by means of animal experiments. The virus must not be highly infective for man and cases in experimental stations are very unusual.

MEAT and MEAT PRODUCTS.

Many research workers have studied the infectivity of carcasses of refrigerated and frozen meats, salted and unsalted.

In an infected muscle, the virus is rapidly destroyed by the increasing acidity but will survive for comparatively long periods in those tissues that do not become more acid than about pH 6.2. (76a).

Virus in cheek or tongue tissue of beef held at $-1^{o}C$ may persist for 33 days, however, and in meat-wrapping cloths for 40 days (75a). Quick-freezing of beef suspends acid formation and active virus was demonstrated for so long as the meat was kept frozen. The wrapping cloths of such meat are also likely to be a greater danger than the cloths from chilled or frozen carcasses. Thawing of quick frozen meat initiates the suspended acid formation at an accelerated rate and rapidly produces a medium unsuitable to virus survival, according to Henderson and al (76a). The record of survival in lymph nodes after $4^{3/4}$ and $5^{3/4}$ months at freezing temperature (76a) is of interest. The virus can also persist for a long time in bone marrow of infected beef carcasses refrigerated or frozen (76 to 80 days as reported by Verge (76b). Lymph nodes and bone marrow must therefore be classed as possible sources of infection in an otherwise "safe" carcass rendered apparently non-infective by the acidity of rigor mortis. Henderson and al (76a) state that liver and kidney, when stored frozen as in the imported meat trade, may be shown to have a high degree of infectivity at 4 or

more months and the virus remains active for at least 24 hrs. after
thawing.

Besides liver, kidney, lymph node, bone marrow, the rueen and
blood from diseased cattle also show prolonged survival of virus even
with delay in freezing and after thawing.

Cottral and al (75a) conclude: Muscle tittue of boned meat is
probably free of virus after storage at 4°C for 3 days. Meat on a
whole carcass may still contain virus after 60 days at 4°C, but none
after 73 days.

In pork, the virus was destroyed after one day at normal holding
t^{o}, but was still present in bone-marrow; in frozen pork at -15°C the
virus remained infective for at least 55 days; in frozen liver and
kidneys (-20°C) the virus was found to persist for 6 months and 8 weeks
respectively. Normal "pickling solutions" have little or no effect on
the inactivation of the virus (75a).

Prevention of FMD.

Verge mentions in his paper (76b) that back in 1926, Kling and
Höger draw attention on the role of inapparent infection in man.
The FMDV, present on the buccal mucous membranes, remains infective
and could contaminate other human beings or susceptible animals.

As far as contamination through milk and dairy products, the
Expert Committee on Milk Hygiene of the World Health Organization (79)
urges the proper pasteurization of milk and, where local or national
regulations permit the use of milk from infected herds, it states
that compulsory heating of the milk, preferably on the farm itself,

should be required.

The spread of FMD by meat and meat products can be mitigated by certain control procedures. It must not be supposed that all susceptible stock coming in contact with infective material will develop the disease as shown by Henderson and al (76a). However, the appearance of the disease in even one animal of a flock or herd may lead to disastrous results in a country with a highly susceptible animal population. In Great Britain, the "Diseases of Animal Order" (boiling of animal foodstuffs, 1947) directs that all waste products of animal origin be boiled before being fed to live stock.

In spite of adequate cooking of meats, it should be remembered that human beings could still get infected by the consumption of pickled meats.

Lymphocytic Choriomeningitis. (LCM)

Although, to our knowledge, the virus of LCM has not been isolated directly from foodstuff or milk, there is strong suspicion that food could be secondary contaminated by the urine or feces of infected house mice. As mentioned by Hull (80), infection via the respiratory tract is suggested by the common early respiratory symptoms. Other possible routes are the gastrointestinal tract by eating of contaminated food or through the skin or conjunctiva.

Top (83) mentions that person to person contact has not yet been demonstrated and the mode of transmission is not certain, but it is probable that it is largely mouse-to-man. The alimentary route cannot be ignored, for the virus is excreted in the urine and feces of mice

and can contaminate food eaten by man or animals.

Rhodes and Van Rooyen (81) also refer to the possibility of ingestion of material contaminated by infected mice excreta.

A large number of reports of well established cases (clinical and laboratory evidence) of LCM have stressed the human contact with house mice from which the LCM virus was successfully isolated.

Rabies.

The virus of rabies is normally spread by the bite of dogs, cats, foxes, wolves, or bats, as well as by other animals. The disease itself has been recorded from early antiquity and may affect almost all mammals. Transmission of rabies by food is very rare, and, in general, authorities on this disease believe that the consumption of meat or milk from a rabid animal is extremely unlikely to initiate rabies in man (86, 87, 90, 92). This is mainly because the virus does not infect via the normal alimentary tract (90), although it may possibly do so via abrasions in the mouth or throat. In addition, rabies is rapidly inactivated by gastric juice (86). The virus is, however, relatively resistant to heat and survives $60^{o}C$ (140 F) for 5 minutes, and $100^{o}C$ for 2-3 minutes (89a).

Milk.

In one case dating from 1886, milk from a young woman previously bitten by a rabid wolf and suffering from acute rabies, was inoculated into 4 rabbits, which all contracted clinical rabies. Inoculation of brain suspensions from these rabbits transmitted the disease to puppies. The woman died one day after the milk samples were taken, but there was no infection in the infant whom she had been nursing until the date before her death (84).

Rabies virus has been isolated experimentally from the milk of rabid animals such as, for example, dogs (86), cows (88), or rabbits (89), but there is little or no evidence that the disease is spread to suckling animals. In one instance it has been suggested that the virus was spread by water infected by the saliva of rabid animals (85).

Pox Viruses. (Cowpox, vaccinia, pseudocowpox, smallpox.)

That food may be contaminated by the virus of cowpox (primary contamination), vaccinia and smallpox (secondary contamination) is a possibility and therefore deserves mention in this report.

The Expert Committee on Milk Hygiene of the World Health Organization (93) states that "milk can serve as a vehicle for transmission of cowpox, vaccinia and pseudocowpox by contact rather than ingestion. Since the lesions characterizing these diseases cannot be distinguished clinically, veterinary advice on herd treatment should be sought and the milk should be pasteurized. Milk should not be used from cows showing active lesions (pustules, serous scabs) on the udders".

In a very recent book (1962) by Dixon (94) on smallpox, it is mentioned: "Although some of the older writers pointed out that infection might be conveyed by food, as variolation can occur from consuming smallpox virus in the form of scabs, this route is of no practical importance". Boyd (cit.94) relates how a man milked a herd of cows for a town milk supply whilst he was suffering from smallpox but it did not give rise to any cases.

Finally, in Rhodes and Van Rooyen's textbook (95) the statement

that the virus of smallpox is present in the upper respiratory tract of the patient, and the infection can be transmitted by droplets or by salivary contamination of eating or drinking utensils, deserves attention.

All these viruses belong to a group of agents exceptionally resistant to changes in temperature and to dessication and it seems wise to presume that they could, under certain rare circumstances, contaminate foodstuff and milk.

Newcastle Disease Virus.

Although Newcastle Disease Virus (NDV) may cause human disease, no cases in our knowledge, of clinically or laboratory established infection in humans have been connected with the consumption of food contaminated with this virus.

However, because the NDV has been found, according to Hull (96), to be present in the yolk sac of 4 day old chicks, embryos and infertile eggs laid by hens during the active stages of infection, the NDV should presumably be included in Class IV, as described above.

Pierce (97), in an interesting study of the recovery of NDV from experimentally contaminated baby foods succeeded in recovering approximately 100% of the virus ,using tissue culture techniques. When these foods were stored at $-20^{\circ}C$ for 2 weeks, the foods had a "protective effect" on NDV; this effect was still observed when the foods were subjected to 4 freeze-thaw cycles for 2 weeks, although, in this case, the virus titer was lower than in the case of storage at $-20^{\circ}C$ for the same time.

TABLE 2

THE CONTAMINATION OF FOOD BY VIRUSES AND RICKETTSIAE.

FOOD		ORGANISM	REFERENCES
MILK			
	Cow	Poliovirus	1,2,3,4,5,6,11.
		Foot-and-mouth disease	75b, 76b, 77.
		Infectious Hepatitis	16.
		Russian tick-borne complex (?)	73.
		Poxviruses (?)	93.
		Q fever	36, 39,40,45,46,47,49,50, 51, 52,56,57,60,61,62,65,66.
	Goat	Russian tick-borne complex	69,70,71,72,73,74.
		Q fever	39,44,57,58,66.
	Sheep	Q fever	44,48,55,58,63.
	Dog	Rabies	86.
	Human	Rabies	84.
		Q fever	38.
CREAM-BUTTER			
		Foot-and-mouth disease	76b,77.
		Q fever	38,53.
CHEESE (cow's milk)		Foot-and-mouth disease	76b,77.
		Q fever	38.

TABLE 2 (continued)

THE CONTAMINATION OF FOOD BY VIRUSES AND RICKETTSIAE.

FOOD	ORGANISM	REFERENCES
MEAT-MEAT PRODUCTS		
Beef	Foot-and-mouth disease	75a, 76a, 76b.
	Q fever (experimental)	42.
Pork	Foot-and-mouth disease	75a, 76b.
Beef tongue	Foot-and-mouth disease	75a.
Beef liver and kidney	Foot-and-mouth disease	75a, 76a.
EGGS	Q fever (experimental)	36,37.
MISCELLANEOUS		
Oysters	Infectious Hepatitis	12b,14,14a,18,19.
Clams	Infectious Hepatitis	12a,13,18.
Bananas	Poliovirus (experimental)	10.
Lemonade	Poliovirus	7.

=================

CONCLUSIONS.

To the best of our knowledge, this report is the first compre-
hensive review of those viruses and rickettsiae which may contaminate
food, and which may subsequently initiate infection in man. The only
related review is that by Brown in 1949, which dealt with viral infections
spread via milk and water (98).

Although many text-books and reports have discussed the problem of
viral food contamination in general terms, critical study of the litera-
ture has shown that there is in fact very little, if any, convincing
laboratory evidence in many of these cases. We have therefore limited
the review to those viruses which, in our judgement, are definitely
proven to be associated with food-borne infections in man, either by
clear-cut laboratory evidence or by very strong epidemiological evidence.

Under the classification proposed in the Introduction (Table I),
there are thus 4 viruses (poliovirus, foot-and-mouth disease virus,
rabies virus, and the Russian tick-borne viruses) and one rickettsia
·(Q fever) which fall in Class I, i.e. agents which have been isolated
directly from infected foods of various kinds in the laboratory. In-
fectious hepatitis is the single example in Class II; there is a wealth
of epidemiological evidence connecting this virus with human infections
contracted through consumption of sea-food, in particular. The recent
cultivation of this virus in Detroit cells, as mentioned above, opens
the way to direct studies on the possibility of isolating infectious
hepatitis virus from infected foods. The viruses in Class III, namely
cowpox, epidemic viral diarrhea, lymphocytic choriomeningitis, small-
pox, and vaccinia, are very probably responsible for human infection

through ingestion of contaminated food, but much remains to be done in
obtaining completely unequivocal laboratory evidence. The Newcastle
Disease virus of chickens was included (Class IV) because it is the
only virus which was deliberately mixed with various types of food in
the laboratory and then recovered at various time intervals. This virus
is widespread in poultry, but infection in man is extremely rare and has
never been recorded via food.

There are thus 10 viruses and 1 rickettsia which are capable of
contaminating food and initiating infection in man. The origin of con-
tamination may be primary (Q fever, rabies, foot-and-mouth disease,
Russian tick-borne complex; probably cowpox), or secondary (polio-
myelitis, infectious hepatitis, epidemic diarrhea; probably lymphocytic
choriomeningitis, smallpox and vaccinia). It would be possible to
speculate, though hardly profitable here, that many other viruses, e.g.
Murray Valley Fever, rinderpest, hog cholera, Teschen disease (pigs),
adenoviruses (human and pigs), and possibly the influenza-mumps group
of viruses, could be transmitted by food. But we have been unable to
discover any laboratory or epidemiological evidence on this, despite
exhaustive search of the literature and consultation of many authorities.

It is interesting that viruses of all sizes and many types are
represented in Table I, from the smallest known animal viruses (in-
fectious hepatitis, foot-and-mouth disease) to the largest (poxviruses).
Viruses that normally multiply in the alimentary tract (polimyelitis)
would seem to have a clear advantage for infection by ingestion, yet
Q fever, which is normally spread by inhalation or tick-bite, has also
been relatively frequently recorded in food (Table 2). It is note-
worthy that strictly respiratory viruses (influenza, adenoviruses,

common cold) are absent from the list.

Table 2 lists the collected data under the headings of various foods. It is immediately clear that milk of various types is by far the most frequent vehicle for virus infections in man. The two instances of transmission by human milk, namely rabies and Q fever, are of interest.

Q fever and foot-and-mouth disease have also been transmitted by cream, butter and cheeses. With meat and meat products, foot-and-mouth disease is the only virus that has been widely found, in some cases even after weeks or months of cold-storage. This disease is of very little significance in man. Infectious hepatitis is the classic example of a food-borne virus, and is very frequently the unpleasant sequel of eating raw oysters or clams.

It should be noted that normal cooking, or fully efficient pasteurization of milk, would certainly inactivate all the viruses mentioned above. Q fever, infectious hepatitis, and rabies are unusually heat-stable organisms, and are therefore likely to survive inefficient pasteurization or partial cooking. The effects of ionizing radiation on the inactivation of these viruses are discussed in Part II of this review.

PART II

SUMMARY OF RADIATION EFFECTS ON FOOD-BORNE VIRUSES

We have shown in the preceding section that nine viruses, namely foot-and mouth disease, infectious hepatitis, lymphocytic choriomeningitis (LCM), Newcastle disease, poliomyelitis, rabies, Russian Spring-Summer encephalitis, and vaccinia-variola, have definitely been shown to cause human infection via food. Only one rickettsia, namely Q-fever, is certainly transmitted by food.

We have been unable to discover any references in the extensive literature that we have reviewed that deal with the direct radiation of viruses present in food. However, all these agents, with the exception of infectious hepatitis, LCM, and Q-fever, have been irradiated by various types of ionizing particles in the laboratory. Russian Spring-Summer fever has itself not been irradiated, but data on comparable types of encephalitis viruses are discussed below.

The general effects of ionizing radiation on animal virus were reviewed and discussed by the author in 1959. (McCrea, 1960). Since that time relatively few papers on this subject have appeared. Recently, we came across some extremely interesting early work on the irradiation of vaccinia, poliovirus, and foot-and-mouth disease, which is described in a French textbook on virus diseases of animals (Les Ultravirus des Maladies Animales, Paris, 1943). The original papers, which appeared in Paris in 1940-1942, have been read and abstracted. As far as we are aware, this work has never been mentioned in the English literature.

Radiation data on food-borne viruses are recorded in Table 3.
Following the virus type, the table presents the condition of the virus
(i.e., wet, dry, or frozen), the type of radiation involved, and the
inactivation doses. There is some difficulty in comparing "inactivation"
dose as described by various authors. Much research on the effects of
radiation on viruses has been concerned with the magnitude of the dose
of various types of radiation required to cause partial virus inacti-
vation, since from these doses it is possible to calculate the dimen-
sions of the "radiosensitive infectious unit" (see Lea and Salaman,
1942; Bonét-Maury, 1942, 1943; Pollard, Rev. Mod. Phys. 31, 273-281,
1959; and McCrea, 1960). Bonét-Maury introduced the factor $\Delta 10$, i.e.,
that dose of radiation which reduced the virus survival to 10% of the
original titer. From this value he calculated the diameter of the
radiosensitive target; these diameters in many cases (e.g., vaccinia,
herpes simplex, and foot-and-mouth disease) closely approach the total
diameters of the virus particles, which at the time of Bonét-Maury's
experiments were doubtful or unknown. Later workers (e.g., Lea and
Salaman) based their calculations on the radiation dose giving 37%
virus survival (D_{37}). Calculations from this value are believed to
give more reliable estimates of radiosensitive dimensions, which are
in many cases considerably smaller than the virus particles themselves.
As pointed out by McCrea (1960), for all viruses larger than 45μ in
diameter the radiosensitive target volume is constant at 45-50μ in
diameter, irrespective of the size of the entire virus particle. This
means that very large viruses, such as herpes simplex or vaccinia, are

inactivated by approximately the same radiation dose as smaller viruses of the size of influenza, Newcastle disease, and certain tumor viruses. Very small viruses, e.g., foot-and-mouth disease, poliovirus, and presumably infectious hepatitis, require relatively larger doses of radiation to reach the 37% survival point. In these cases, the radiosensitive volumes and the total virus volumes are identical, within experimental error.

For the purposes of this review, the total inactivation dose of radiation is obviously the more important value to know, i.e., that radiation dose which is highly probable to kill a certain virus completely, and hence to "sterilize" food in which the virus may be present. The total inactivation dose has been measured by certain workers for some viruses, but it has not been established for all the viruses included in Table 3. However, as mentioned above, since all viruses above 45μ in diameter show a constant value for the dimensions of the radiosensitive unit (calculated from the D_{37} value), it follows that, with a very high degree of probability, the total inactivation dose should also be a constant value for these viruses. This is because the slopes of the inactivation curves are all exponential, or very close to exponential, throughout the inactivation range studied. Hence the extrapolation to zero survival should be constant, within the experimental error of the sensitivity of the assay for the virus concerned. The viruses included in this group, of interest to the present report, are therefore LCM, Newcastle disease, rabies, and vaccinia-cow-pox-small-pox; Q-fever, which is approximately 500μ x 250.μ,

would presumably be completely inactivated by similar, or possibly smaller, doses of radiation.

The viruses of infectious hepatitis (12-18μ), foot-and-mouth disease (20-22 μ), Russian Spring-Summer fever (15-25μ), and poliomyelitis (26-29μ) are in the group of smaller viruses which would require higher radiation doses for complete inactivation. Of this group, poliomyelitis is the only virus for which total inactivation has been experimentally determined (Table 3).

Total Virus Inactivating Dose of Ionizing Radiation

It will be seen from Table 3 that, as discussed in the above section, the total inactivating dose is approximately constant for those viruses in which it has been experimentally determined. This dose is of the order of 1-4 x 10^6 roentgens. In other words, exposure of virus-containing material to a dose of say 5 x 10^6 r should reduce the infectivity titer of virus present to a level which cannot be detected by the most sensitive laboratory assay. The actual values determined are as follows: poliovirus, 2.5-4 x 10^6r; rabies, 0.9 x 10^6r; equine encephalitis, 2-4 x 10^6r; vaccinia, 1-3 x 10^6r. It should be stressed that these figures were obtained by various authors, using viruses of different purity assayed by different techniques. It is, therefore, all the more remarkable that the total inactivation doses are so uniform.

For those viruses on which no direct data are available, certain predictions can be made, as discussed in the above sections. Thus,

TABLE 3

RADIATION DATA ON ANIMAL VIRUSES OCCURRING IN FOOD

Virus	Conditions	Radiation	Partial Inactivation Dose	Total Inactivation Dose	Calculated Dimensions	Reference
Foot-and-mouth	Wet	Radon	$\Delta 10^* = 600\mu\text{rd/cc}$	—	40μ diam.	Bonét-Maury (1943)
Foot-and-mouth	Frozen ~-60°	Co^{60}	$D_{37} = 5\times10^5\text{r}$	—	20μ diam.	Brdish (personal communication)
Newcastle disease	In vacuo	x-rays, electrons, deuterons	—	—	98μ diam.	Woese and Pollard (1954)
Newcastle disease	In vacuo	Deuterons, protons alpha particles	$D_{37} = 6 \times 10^4$	—	56μ diam.	Wilson and Pollard (1958)
Poliovirus	Wet	Radon	$\Delta 10 = 96\mu\text{rd/cc}$	—	100μ diam	Bonét-Maury (1942)
Poliovirus	In vacuo	Deuterons, alpha particles	—	—	31μ diam.	Pollard and Kraft (1955)
Poliovirus	Frozen ~-60°	Co^{60}	—	$3\text{-}4 \times 10^6\text{rep}$	—	Jordan and Kempe (1956)
Poliovirus	In vacuo or -60°	Deuterons, alpha particles, electrons	—	$2.5 \times 10^6\text{r}$	28μ diam.	Benyesh, Pollard, et al (1958)
Rabies	Frozen ~60°	Electrons	—	$8.5 \times 10^6\text{ rep}$	—	Traub, et al (1951)
Equine Encephalitis	Frozen ~-60°	Co^{60}	—	$2\text{-}4 \times 10^6\text{ rep}$	—	Jordan and Kempe (1956)
Equine Encephalitis	Frozen <60°	Electrons	—	$4 \times 10^6\text{ rep}$	—	Bellamy et al (1957)

TABLE 3 (Continued)

Virus	Conditions	Radiation	Partial Inactivation Dose	Total Inactivation Dose	Calculated Dimensions	Reference
Vaccinia	Wet	X-ray	—	3×10^6 r	—	Gowen and Lucas (1939)
Vaccinia	Wet	Radon	$\Delta 10 = 13.5 \mu cd/cc$	—	260μ diam.	Bonet-Maury and Perault (1941)
Vaccinia	Dry	X-rays	$D_{37} = 1 \times 10^5$ r	1×10^6 r	34μ diam.	Lea and Salaman (1942)
Vaccinia	Dry	Alpha particles	$D_{37} = 2 \times 10^5$ r	1.5×10^6 r	33μ diam.	Lea and Salaman (1942)
Vaccinia	Dry	Gamma Rays	$D_{37} = 0.8 \times 10^5$ r	6×10^5 r	36μ diam.	Lea and Salaman (1942)
Vaccinia	Dry	Gamma rays	$D_{37} = 0.4 \times 10^5$ r	—	46μ diam.	McCrea (1960)
Vaccinia	Dry	1 Mev electrons	$D_{37} = 0.3 \times 10^5$ r	—	50μ diam.	McCrea (1960)
Vaccinia	Dry	Gamma rays	$D_{37} = 0.7 \times 10^5$ r	—	$25-36 \mu$ diam.	Wilson (1961)

* $\Delta 10$ = dose reducing survival to 10% control   — not determined

† D_{37}= dose reducing survival to 37% control.

Newcastle disease, which has a D_{37} dose similar to that for vaccinia and the larger virus group, would certainly be completely inactivated by 5×10^6 r. Foot-and-mouth disease and Russian Spring-Summer fever, which are slightly smaller than poliovirus, should be inactivated completely by a slightly higher radiation dose, say $5-6 \times 10^6$ r.

The virus about which there is the greatest uncertainty is that of infectious hepatitis. This virus has been isolated and character- ized only very recently (November 1961) and no radiation data are as yet available*. However, from the above discussion one could predict that a virus 15μ in diameter would have a D_{37} dose of approximately 1×10^6 r. If the virus is inactivated exponentially, it follows that only 0.00001% would survive radiation by 1.4×10^7 r, which is equiv- alent to "total inactivation" as determined for other viruses, i.e., a fall in titer of 6 log-units. Allowing for errors in the assump- tions made, it could safely be concluded that infectious hepatitis would be completely inactivated by radiation doses of 2×10^7 r.

Practical Problems in Irradiating Viruses in Foods

The doses mentioned above for completely inactivating viruses, $5 \times 10^6 - 2 \times 10^7$ r, are of similar order to those used for irradiating foods. It should be mentioned that it is well known that viruses are partially protected against radiation inactivation in concentrated protein suspensions, such as occur in milk or in meat. However, the

*There is some evidence that infectious hepatitis virus present in blood plasma is destroyed by ultraviolet-irradiation. Inactivation of the virus by this means is currently thought to be unreliable, and it is obviously not applicable to virus in foods.

data given above are calculated as for "dry" viruses, which give the maximum inactivation doses, at least as great or greater than those occurring wet in concentrated protein. The doses of $5 \times 10^6 - 2 \times 10^7 r$ are, therefore, directly applicable to viruses in the "wet" state as in foods.

In the laboratory, viruses are usually irradiated in thin films. For foods in bulk it is obviously necessary that virus in the interior of a can of meat, for example, be completely irradiated. Radiations of high penetrating ability, such as gamma rays or very high-energy accelerated particles, would be necessary.

The undesirable tastes and odors that arise in foods following the doses of radiation required to inactivate viruses are outside the scope of this report, but obviously constitute an important practical problem.

REFERENCES

Poliomyelitis

1. Aycock,W.L. A milk borne epidemic of poliomyelitis.
   Am. J. Hyg.1927, $\underline{7}$:791-803.

2. Dingman, J. C. Report of a possibly milk-borne epidemic of
   infantile paralysis. N.Y. State J. Med. 1916, $\underline{16}$:589-590.

3. Goldstein, D.M., Hammon, W. McD., and Viets, H. R. An out-
   break of poliomyelitis among navy cadets, possibly food borne.
   J. A. M. 1946, $\underline{131}$:569-573.

4. Hargreaves, E. R. Epidemiology of Poliomyelitis. The Lancet,
   June 4, 1949, p. 969.

5. Jubb, G. A third outbreak of epidemic poliomyelitis at West
   Kirby. Lancet, 1915, $\underline{1}$:67.

6. Knapp, A. C., Godfrey, E.J. Jr. and Aycock, W. L. An out-
   break of poliomyelitis apparently milk-borne. J.A.M.A. 1926,
   87:635-639.

7. Piszczek, E. A., Shaughnessy, H.J., Zichis, Jr. and Levinson,
   S.O. Acute anterior poliomyelitis: Study of an outbreak in
   West Suburban Cook County, Ill.-Preliminary Report. J.A.M.A.
   1941, $\underline{117}$:1962.

8. Fly borne poliomyelitis virus on food. Symposium Section-
   Internat. Digest, 1945, $\underline{47}$:55-58.

9. Toomey, J. A., Takacs, W.S. and Tischer, L.A. Attempts to
   find poliomyelitis virus in fish. Pros. Soc. Exp. Biol. and
   Med. 1945, $\underline{58}$:152-154.

10. Ward, R., Melnicl, J. L. and Horstmann, D.M. Poliomyelitis
    virus in fly-contaminated food collected at an epidemic.
    Science 1945, $\underline{101}$:491-493.

11. World Health Organization Technical Report Series n° 124,1957,
    Geneva. Joint FAO/WHO Expert Committee on Milk Hygiene.

Infectious Hepatitis

12a. Dougherty, W. J. and Altman, R. Viral Hepatitis in New Jersey
     1960-1961. Am. J. Med. 1962, $\underline{32}$:704-716.

12b. Gard, S. and Alin, K. Hepatitis Frontiers, 1957, p. 169. Studies on the Hepatitis virus. (Edit. by Hartman, F. W. and all. Boston, Little.)

13. Hepatitis Surveillance Report n°5, May 3, 1961, Communicable Disease Center, U.S. Public Health Service, Dept. of Health, Educ. and Welfare.

14a. Mason, J. O. and McLean, W. R. Infectious Hepatitis traced to the consumption of raw oysters. An epidemiologic study. Am. J. of Hyg. 1962, 75:90-111.

14. Hepatitis Surveillance Report n°5, May 3, 1961, Communicable Disease Center, U. S. Public Health Service, Dept. of Health, Educ. and Welfare.

15. Kirk, R. Spread of infectious Hepatitis. Lancet 1945, 1:80.

16. Murphy, W. J., Petrie, L.M. and Work, S. D. Jr. Outbreak of infectious Hepatitis, apparently milk borne. Am. J. Publ. Health 1946, 36:169-173.

17. Read, M. R., Bancroft, H., Doull, J.A. and Parker, R.F. Infectious Hepatitis presumedly food borne outbreak. Am. J. Publ. Health 1946, 36:367-370.

18. Rindge, M. E. Infectious Hepatitis and its relation to polluted shellfish. Conn. Health. Bull. 1961, 75:217-222.

19a. Rightsel, W. A., Keltsch, R.A., Taylor, A.R., Boggs, J.D. and McLean, I. M. Status report on tissue-culture cultivated hepatitis virus. I. Virology Laboratory studies. J.A.M.A. 1961, 177:671-678.

19. Roos, B. Hepatitepidemi, spridd genom ostron (Epidemic hepatitis transmitted by oysters). Svenska Läkartidningen 1956, 53:989-1003. (Stockholm).

20. Van Rooyen, C. E. and Kirk, G. R. The spread of infective hepatitis and polio in Egypt. Edinburgh Med. J. 1946, 53:529.

21. World Health Organization Technical Report Series n° 124,1957, Geneva. Joint FAO/WHO Expert Committee on Milk Hygiene.

Epidemic Diarrhea-Viral Gastro-enteritis

22. Light, J.S. and Hodes, H. L. Studies on epidemic diarrhea of the newborn: isolation of a filtrable agent causing diarrhea in calves. Am. J. Publ. Health, 1943, 33:1451.

23. Cummings, G.D. Epidemic diarrhea of the newborn from the point of view of the epidemiologist and bacteriologist. J. of Ped. 1947, 30:706.

24. Buddingh, G. J. and Dodd, K. Stomatitis and diarrhea of infants caused by hitherto unrecognized virus. J. of Ped. 1944, 25:105

25. Gordon, L., Ingraham, H.S. and Korns, R.F. Transmission of epidemic gastroenteritis to human volunteers by oral administration of fecal filtrates. J. Exp. Med. 1947, 86:409.

26. Jordan, W. S., Gordon, L. and Dorrance, W. R. A study of illness in a group of Cleveland families. VII. Transmission of acute non bacterial gastroenteritis to volunteers: evidence for two different etiologic agents. J. Exp. Med. 1953, 98:461.

27. Reimann, H. A., Price, A. H. and Hodges, J. H. The cause of epidemic diarrhea, nausea and vomiting (viral dysentery?) Pros. Soc. Exp. Biol. and Med. 1946, 59:8.

28. Gordon, J. E. and Rubinstein, A. D. Epidemic diarrhea of the newborn. Am. J. Med. Sci. 1950, 220:339.

29. Gordon, J. Gastroenteritis: the aetiological importance of viruses and bacterioum coli. Human virus studies. Pros. Roy. Soc. Med. 1954, 47:1067.

30. Goodall, J.F. The winter vomiting disease. A report from general practice. Brit. Med. J. 1954, 1:197–198.

31. Clifford, S. H. Diarrhea of the newborn: its causes and prevention. N.E.J.M. 1947, 237:969–976.

32. Pond, M.A. and Hathaway, J.S. An epidemic of mild gastroenteritis of unknown etiology presumably spread by contaminating eating utensils. Am. J. Publ. Health 1947, 37:1402–1406.

33. Daver, C. C. and Davids, D.J. 1959 Summary of disease outbreaks. Publ. Health Report 1960, 75:1025–1030.

34. Ramos-Alvarez, M. and Sabin, A.B. Enteropathogenic viruses and bacteria. J.A.M.A. 1958, 167:147.

35. Kaplan, A. S. and Melnick, J. L. Effect of milk and other dairy products on the thermal inactivation of Coxsackie viruses. Am. J. of Publ. Health, 1954, 44:1174–1184.

Q Fever

36. Abinanti, F. R. The varied epidemiology of Q fever infections.
    Symposium on Q fever by the Commission on Rickettsial Diseases,
    Armed Forces Epidemiological Board. Edit. by Smadel, J. E.
    Medical Science publication n°6, 1959. Walter Reed Army Inst.
    of Res., Walter Reed Army Med. Center, p. 8-11.

37. Abinanti, F. R. and Marmion, B. P. Protective or neutrali-
    zing antibody in Q fever. Am. J. Hyg. 1957, 66:173-195.

38. Babudieri, B. Epidemiology, diagnosis, and prophylaxis of
    Q fever. Advances in the control of Zoonoses; Bovine Tuber-
    culosis-Brucellosis-Leptospirosis-Q fever-Rabies. WHO/FAO
    Seminar on Zoonoses, Vienna 1952. WHO Monograph series n°19,
    1953, Geneva. p.157-174.

39. Beck, M. D., Bell, J. A., Shaw, E. W. and Huebner, R. J.
    Q fever studies in Southern California. II An epidemiological
    study of 300 cases. Publ. Health Rep. 1949, 64:41-56.

40. Bektemirov, T. A., Tarasevich, I. V. and Karulin, B. E. A
    study of an epidemic focus of Q fever in the Crimea. Zhurnal
    Mikrobiologii Epidemiologii i Immunobiologii. Moscow 1956,
    11:20-26. (Abstract in Trop. Dis. Bull. 1957, 54:553-554.

41. Bell, J. A., Beck, M. D. and Huebner, R. J. Epidemiologic
    studies of Q fever in South California. J.A.M.A. 1950,
    142:868-872.

42. Bell, E. J., Parker, R. R. and Stoenner, H. G. Q fever,
    experimental Q fever in cattle. Am. J. Publ. Health 1949,
    39:478-484.

43. Berge, T.O. MSC. Public Health importance of Q fever.
    Medical Science Publication n°6, 1959, p. 15-19. Symposium
    on Q fever by the Commission on Rickettsial Dis., Armed
    Forces Epidem. Board. Edit. by Smadel, J.E. Walter Reed
    Army Institute of Research, Walter Reed Army Med. Center.

44. Caminopetros, J. Q fever (Balkan grippe). Abstract of paper
    presented before the IV Intern. Cong. on Trop. Med. and
    Malaria, 1948, Washington, D.C.

45. Enright, J. B., Sadler, W. W. and Thomas, R. C. Thermal in-
    activation of Coxiella Burnetii in milk pasteurization.
    Publ. Health Service Monograph n° 47, 1957. (Publ. Hlth.
    Serv. Public.n° 517).

46. Evans, A. D. Q fever in South Wales. Monthly Bull. Ministry
    of Health and Public Health Lab. Serv. 1956, 15:215-219.
    (Abstract in Trop. Dis. Bull. 1957, 54:20-21.)

47. Grist, N. R. Q fever in South West Scotland. Scot. Med. J.
    1956, 1:173.

48. Huebner, R. J. and Bell, J. A. Q fever studies in Southern
    California. Summary of current results and a discussion of
    possible control measures. J.A.M.A. 1951, 145:301-305.

49. Huebner, R. J., Jellison, W. L., Beck, M. D., Parker, R.R. and
    Shepard, C.C. Q fever studies in Southern California. I
    Recovery of Rickettsia Burnetii from raw milk. Publ. Health
    Rep. 1948, 63:214-222.

50. Irons, J. V., Bads, R.B., Johnson, C. W., Walker, O. L. and
    Norris, M.A. Southwest Texas Q fever studies. J. of Parasit.
    1952, 38:1-5.

51. Irons, J.V., Bads, R.B. and Peavy, J. E. Q fever in Texas.
    Texas Reports Biol. Med. 1957, 15:896-903.

52. Irons, J. V., Murphy, J. N., Rich, A. B. and Hill, A. E.
    Q fever survey in Southwest Texas. Am. J. Publ. Health,
    1949, 39:484-491.

53. Jellison, W. L., Huebner, R. J., Beck, M. D., Parker, R. R.
    and Bell, B. J. Q fever studies in Southern California. VIII.
    Recovery of C. Burneti from Butter made from naturally infected
    and unpasteurized milk. Publ. Health Rep. 1948, 63:1712-1713.

54. Jellison, W. L., Ormsbee, R., Beck, M.D., Huebner, R. J.,
    Parker, R. R. and Bell, B.J. Q fever studies in Southern
    California. V. Natural Infection in a dairy cow. Publ.
    Health Rep. 1948, 63:1611-1618.

55. Jellison, W. L., Welsh, H.H., Elson, B. E. and Huebner, R.J.
    Q fever studies in Southern California. XI Recovery of C.
    Burneti from milk of sheep. Publ. Health Rep. 1950, 65:395-399.

56. Kitze, L. K. Q fever in Wisconsin. Serological evidence of
    infection in cattle and in human beings and recovery of
    Coxiella Burneti from cattle. Am. J. Hyg. 1957, 65:239-247.

57. Lennette, E. H. and Clark, W. H. Observations on the epidem-
    iology of Q fever in Northern California. J.A.M.A. 1951,
    145:306.

58. Lennette, E. H., Clark, W. H. and Dean, B. H.   Sheep and goats in the epidemiology of Q fever in Northern California. Am. J. Trop. Med. 1949, 29:527-541.

59. Luoto, L.   Report on the nationwide occurence of Q fever infections in cattle.   Publ. Health Rep. 1960, 75:135-140.

60. Luoto, L., Huebner, R. J. and Stoenner, H. G.   Q fever studies in Southern California.   XII. Aureomycin treatment of dairy cattle naturally infected with C. Burneti.   Publ. Health Rep. 1951, 88:199-204.

61. Marmion, B. P. and Harvey, M.S.   The varying epidemiology of Q fever in the Southeast region of Great Britain.   In an urban area.   J. Hyg. 1956, 54:533-546.

62. Marmion, B. P. and Stoker, M. G. P.   Q Fever in Great Britain. Epidemiology of an outbreak.   Lancet 1950, 2:611.

63. Marmion, B. P. and Stoker, M.G. P.   The varying epidemiology of Q fever in the Southeast region of Great Britain.   II. In two rural areas.   J. Hyg. (Camb.) 1956, 54:547.

64. Marmion, B. P. and Stoker, M. G. P.   The epidemiology of Q fever in Great Britain.   An analysis of the findings and some conclusions.   Brit. Med. J. 1958, 2:809-816.

65. Marmion, B. P., Stoker, M. G. P., McCoy, J. H, Malloch, R. A. and Moore, B.   Q fever in Great Britain.   An analysis of 69 sporadic cases with a study of the prevalence of infection in humans and cows.   Lancet 1953, 1:503.

66. Slavin, G.   Q fever: The domestic animal as a source of infection for man.   Vet. Rec. 1952, 64:743-753.

67. Sobeslavsky, O.   Experimental infection of the domestic fowl (Gallus gallus domesticus) with Rickettsia burneti.   Ceskoslav. Epidemiol. Mikrobiol. Immunol.   Prague, 1957, 6:146-151. (Abstract in Trop. Dis. Bull. 1957, 54:1401.

68. Stoenner, H. G., Lackman, D.B., Jenson, W., Mather, J., Casey, M. and Harvey, K. A.   The role of dairy cattle in the epidemiology of Q fever in Idaho.   J. of Inf. Dis. 1961, 109:90-97.

Russian tick-borne complex (encephalitis)

69. Rhodes, A. J. and Van Rooyen, C. E.   Textbook of Virology. 1958. 3rd. Edit. (The Williams and Wilkins C⁰, Baltimore).

70. Richling, E. Virus meningo-encephalitis in Austria.
I. Epidemiological features. Bull. World Health Org. 1955,
12:521-534.

71. Rivers, T. M. and Horsfall, F. L. Viral and Rickettsial in-
fections of man. 1959. 3rd. Edit. (J. B. Lippincott C^O,
Philadelphia-Montreal) p. 332-333.

72. Smorodintsev. A.A., Drobyshevskaya, A. I., Il'yenko, V. I.,
Alekseyev, B. P., Gulamova, V.P. and Fedorchuk, L. V.
Etiology and epidemiology of a new neurotropic virus in-
fection-biundulant meningoencephalitis, in Smorodintsev, A. A.
Neurotropic Virus Infection, p. 4-37, 1954. (Medgiz, Leningrad.)

73. Van Tongeren, H. A. E., Wilterdink, J. B., Wyler, R. and Richling,
E. Encephalitis in Austria. III. A serological survey followed
up by an epidemiological study in the endemic region of Styria
during the outbreak of 1954. Arch. Ges. Virusforsch. 1954-55,
6;143-157.

74. Verlinde, J. D. Virus Encephalitis in Mitteleuropa. Munch.
M. Woch. 1956, 98:1029-1032.

Foot-and-mouth disease.

75a. Cottral, G. E., Cox, B. F. and Baldwin, D. E. The survival of
foot-and-mouth disease virus in cured and uncured meat.
Am. J. Vet. Res. 1960, 81:228-297.

75b. Flaum, A. Foot-and-mouth disease in man. Acta path. et
microb. scandinav. 1939, 16:197-213.

76a. Henderson, W. M. and Brooksby, J. B. The survival of foot-and-
mouth disease virus in meat and offal. J. of Hyg. 1948,
46:394-402.

76b. Verge, J. Fièvre Aphteuse, in Levaditi, C., Lépine, P. and
Verge, J. Les Ultravirus des Maladies Animales. 1938, p. 265.
(Librairie Malcine, Paris).

77. Van Rooyen, C. E. and Rhodes, A. J. Virus Diseases of Man.
1948. (Thomas Nelson and Sons, New York.)

78. Warren, J. Foot-and-mouth disease, in Rivers, T.M. and
Horsfall, F. L., Jr. Viral and Rickettsial Infections of
Man. 1959. 3rd Edit. p. 896-897. (J.B. Lippincott C^O,
Philadelphia-Montreal.)

79. World Health Organization Technical Report Series n^O 124,1957,
Geneva. Joint FAO/WHO Expert Committee on Milk Hygiene.

Lymphocytic Choriomeningitis

80. Hull, T. G. Diseases transmitted from Animals to Man.
    1955. (C. C. Thomas).

81. Rhodes, A. J. and Van Rooyen, C. E. Textbook of Virology.
    1958. (The Williams and Wilkins C^O, Baltimore).

82. Warren, J. Lymphocytic choriomeningitis in Rivers, T.M.
    and Horsfall, F. L. Jr. Viral and Rickettsial Infections
    of Man. 1959, 3rd. Edit. p. 903. (J. B. Lippincott C^O,
    Philadelphia-Montreal).

83. Top, F. H. Communicable and Infectious Diseases. 1960.
    (The C. V. Mosby C^O).

Rabies

84. Bardach, J. Le virus rabique dans le lait. Ann. Inst. Past.
    1887, 1:180-134.

85. Deshmukh, P. L. Clinical hydrophobia without contact with
    rabies-transmitting animal. Indian Med. Gaz. 1949,
    84:546-548.

86. Hull, T. G. Diseases transmitted from Animals to Man.
    1955. (Charles C. Thomas, Springfield, Ill.).

87. Hutyra, F. and Marek, J. Special Pathology and Therapeutics
    of the Diseases of Domestic Animals. 1926. (Baillière,
    Tindall and Cox, London).

88. Kaufman, R. L. and Davidson, G. P. An experiment on the
    transmission of rabies through milk. Med. Rec. 1937,
    146:509-511.

89a. Mackie and McCartney. Handbook of Bacteriology. A Guide
     to the laboratory diagnosis and control of infection. 1960.
     Edit. by Cruickshank, R. (10th. Edit. E. and S. Livingstone
     Ltd. Edinburgh, London).

89. Levaditi, C. et Lépine, P. Les Ultravirus des Maladies
    Humaines. 1937. p. 450. (Librairie Maloine, Paris).

90. Webster, L. T. Rabies. 1942. p. 24. (N.Y. The Macmillan C^O.)

91. Zagari, G. Expérience sur la transmission de la rage de la
    mère au foetus à travers le placenta et par le moyen du lait.
    Giorn. Int. d. Scienze Mediche, 10° année, 1888. (Ann. Inst.
    Past. 1888, 2:92-94.)

92. World Health Organization Expert Committee on Rabies.
    WHO Technical Report series n° 28, 1950. Report on the
    First session.

Cowpox, vaccinia, smallpox.

93. World Health Organization Technical Report series n° 124,
    1957, Geneva. Joint FAO/WHO Expert Committee on Milk Hygiene.

94. Dixon, C. W. Smallpox. 1962, p. 302. (J. A. Churchill Ltd.)

95. Rhodes, A. J. and Van Rooyen, C. E. Textbook of Virology,
    1958. (The Williams and Wilkins C° Baltimore).

Newcastle disease virus

96. Hull, T. G. Diseases transmitted from animals to man.
    1955 p. 342. (Charles C. Thomas).

97. Pierce, J. S. The recovery of Newcastle disease virus from
    experimentally contaminated foods. 1961. Thesis submitted
    in partial fulfillment of the requirements for the degree
    of Master of Science. Univ. of Mass., Amherst, Mass.

Review

98. Brown, G. C. The possible significance of milk and water
    in the spread of virus infections. Am. J. Publ. Health.
    1949, 39:764-771.

RADIATION REFERENCES

1. Bellamy, W. D., Lawton, E. J. and Gordon, I. Studies on the
    Inactivation of Viruses by High-Velocity Electrons. G. E.
    Research Lab. Report No. 57-RL-1846, 1957.

2. Benyesch, M., Pollard, E. C., Opton, E. M., Black, F. L.,
    Bellamy, W. D., and Melnick, J. S. Size and Structure of
    Echo Poliomyelitis and Measles Viruses Determined by Ionizing
    Radiation and Ultrafiltration. Virology 5, 256-274, 1958.

3. Bonet-Maury, P. Action der Radon sur le Virus Vaccinal:
    Toxicite de l'Eau Irradiee. Comp. Rend. Soc. Biol., 135,
    941-943, 1941.

4. Bonet-Maury, P. Les Ultravirus des Maladies Animales (C.
    Levaditi, P. Lepine, et T. Verge, eds. Paris, Librairie
    Maloine, 1943) p.196-203. Irradiation par le Radon (Polio-
    myelite Sonchehansing), la Vaccine, et l'herpes.

5. Bonet-Maury, P. and Levaditi, C. Evaluation, par Irradiation,
    de la Taille du Virus de la Poliomyelite (Souche Lansing).
    Comp. Rend. Soc. Biol., 136, 481-483, 1942.

6. Bradish, C. J. Inactivation of Foot-and-Mouth Disease Virus
    by Gamma Rays. (Personal communication, 1959).

7. Gowen, J. W. and Lucas, A. M. Reaction of Variola Vaccinia
    Virus to Roentgen Rays. Science 90, 621-622, 1939.

8. Jordan, R. T. and Kempe, L. L. Inactivation of Some Animal
    Viruses with Gamma Radiation from Cobalt 60. Proc. Soc.
    Exp. Biol. Med., 91, 212-215, 1956.

9. Lea, D. E. and Salaman, H. M. The Inactivation of Vaccinia
    Virus by Radiations. Brit. J. Exp. Pathol., 23, 27-37, 1942.

10. McCrea, J. F. Ionizing Radiations and its Effect on Animal
    Viruses. Ann. N. Y. Acad. Sci., 83, 692-705, 1960.

11. McCrea, J. F., Preiss, J. W., and O'Loughlin, J. Physical
    Studies on Pox Viruses. I. Inactivation of Vaccinia Virus
    Infectivity with Low-energy Electrons. Biophys. J. 1, 43-53,
    (1960).

12. Pollard, E. D. and Kraft, L. M. Inactivation of MEF-1
    Poliomyelitis Virus by Ionizing Radiation. Proc. Soc. Exp.
    Biol. 88, 331-333, 1955.

13. Traub, F. B., Friedemann, U., Brasch, A., and Huber, W. High
    Intensity Electrons as a Tool for Preparation of Vaccines
    IΣ Preparation of Rabies Vaccine. U. Immunol. 67, 379–384,
    1951.

14. Wilson, D. E. Radiation Inactivation of Vaccinia Virus.
    Radiation Research 14, 796–802, 1961.

15. Wilson, D. E. and Pollard, E. C. Radiation Studies on the
    Infective Property of Newcastle Disease Virus. Radiation
    Research 8, 131–141, 1958.

16. Woese, C. and Pollard, E. C. The effect of Ionizing Radi-
    ation on Various Properties of Newcastle Disease Virus.
    Arch. Biochem. Biophys., 50, 354-367, 1954.